METRICAL STRESS SENSITIVITY AND READING SKILLS IN ADULTS

By

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ABSTRACT

Speech rhythm emerges from the alternating pattern of stressed and unstressed syllables in spoken language. It contributes to language development by helping with segmentation of the continuous speech signal into discrete linguistic units. There is increasing evidence for a link between speech rhythm perception skills and early reading acquisition. In addition, poor readers and individuals with dyslexia show deficits on speech rhythm tasks. However, it is unclear whether these deficits reflect impaired representations of word stress resulting from auditory processing deficits (i.e., speech rhythm sensitivity), or alternatively, an impaired ability to compare and contrast speech rhythm cues (i.e., speech rhythm awareness). The main research question was to investigate to what extent individual differences in speech rhythm sensitivity and speech rhythm awareness correlate with reading skills. To this end, we developed a revised version of the DEEdee task used by Whalley and Hansen (2006). Participants read written words and listened to pairs of spoken "deedee" pseudowords. They were required to decide which "deedee" was pronounced with the same stress pattern as the written word. Accuracy rate on the task was used as a measure of speech rhythm awareness. Participants' brain responses were recorded using electroencephalography (EEG) and event-related potentials (ERPs) elicited by the matching and mismatching "deedee" pseudowords. They were compared to measure speech rhythm sensitivity. Participants' scores on the English and Reading sections of the ACT were used as literacy outcome measures. Results showed significant differences between the brain responses associated with the “deedee” pseudowords with matching and mismatching stress patterns. In addition, increased awareness to the least common stress pattern in English was found to be significantly correlated with reading skills. In contrast, stress rhythm sensitivity did not correlate with any of the reading measures. These findings favor the view that poor readers may not have impaired prosodic representations, but rather deficits in their ability to access and/or manipulate these representations.

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CHAPTER ONE

INTRODUCTION

For the past few decades, phonology, the study of the language sound system has been a prominent focus in the field of reading research. Phonology can be further divided into two subparts: segmental and suprasegmental (Schreiber, 1991). Segmental phonology focuses on individual speech sounds (i.e., phonemes such as vowels and consonants), their basic properties (i.e., distinctive features) as well as how they combine with one another in a given language (i.e., phonotactic rules). Suprasegmental phonology, also known as prosody, focuses on phonological properties that superimpose on speech segments that may include multiple phonemes (Ramus, 2001). Prosody encompasses a wide array of complex phonological phenomena (Cutler, Dahan, & van Donselaar, 1997). For instance, from a phonetic point of view, prosody is characterized by changes in acoustical features such as fundamental frequency (vocal pitch), intensity (loudness), or phoneme and syllable duration. From a phonological point of view, combinations of these acoustic features form the basis of prosodic units such as length, accent, and tone (Fox, 2000). While prosody may function as a universal linguistic subsystem across many languages (e.g., vocal pitch rises at the end of questions and falling at the end of statements), each language also has unique prosodic properties, allowing us, for instance, to distinguish British English from American English (Frazier, Carlson, & Clifton, 2006). Several linguistic theories have been proposed to explain prosody in terms of phrasing, rhythm, intonation, and stress (Beckman & Pierrehumbert, 1986; Ladd, 1980; Liberman & Prince, 1977; Nespor & Vogel, 1986; Selkirk, 1986). Directly related to the present study, stress is the mark of emphasis given to a sound or syllable in spoken language. It is also called lexical stress or word stress. Languages such as English are considered to have variable stress because the position of the stress in a word is lexically determined (Hirst & Di Cristo, 1998). In addition to providing cues that guide segmentation of the speech signal (Cutler et al., 1997), stress patterns can be particularly useful to assist them in distinguishing between lexically ambiguous words such as *permit*, which is usually stressed on the first syllable when it is a noun but stressed on the second syllable when it is a verb.

Despite the clear distinction that exists in the phonological literature between segmental and suprasegmental aspects (e.g., Nespor & Vogel, 1986), a great deal of previous research examining the relationship between phonological awareness (PA) and reading abilities has primarily been concentrated on the segmental aspects. There is indeed plenty of evidence supporting that PA is an essential component for the development of young readers (Goodman, Libenson, & Wade-Woolley, 2010) and that many cases of reading difficulty are associated with deficits in PA (Goswami & Bryant, 1990). However, recent research also showed that readers with poor reading achievement might also have limited sensitivity to certain aspects of prosody such as lexical stress patterns, suggesting the possibility that deficits in PA might conceivably be secondary to another more basic auditory deficit (e.g., Clin, Wade-Wooley, & Heggie, 2009; Holliman, Wood, & Sheehy, 2008, 2010a, 2010b, 2012; Whalley & Hansen, 2006; Wood, 2006; Wood & Terrell, 1998). As Goodman et al. (2010) asserted, there are still questions that need to be addressed to explain why PA cannot account for all of the variance in reading competence, even though PA has been found to be a significant predictor for later reading development or achievement. Goodman and his colleagues (2010) proposed that poor prosodic sensitivity is one of the most prominent emerging alternative explanations of the last decade. The current study thus focused on the rhythmic aspects of prosody, and more specifically on how speech rhythm perception skills relate to reading comprehension.

Finally, it should be noted that this relationship is not limited to perception. Prosodic characteristics of children reading aloud (i.e., reading prosody) have also been found to correlate with their reading ability. For instance, in a longitudinal study, Miller and Schwanenflugel (2008) found that children who read aloud with 'adult-like' prosody at the end of first and second grades were more fluent readers and had better reading comprehension one year later. This was in line with the findings from Schwanenflugel, Hamilton, Kuhn, Wisenbaker, and Stahl (2004) showing that children who produced fluent prosody also had better comprehension skills.

Purpose of the Study

The aforementioned literature reviewed evidence supporting the idea that speech rhythm perception skills play an essential role in reading acquisition. While research has been conducted primarily on young readers, usually before the age of 9, a few studies also suggest that prosodic sensitivity still contributes to skilled reading in adulthood (e.g., Mundy & Carroll, 2012). However, the role of prosodic skills in adult readers remains largely underexplored. The purpose of the present study was to address these issues by exploring the association between speech rhythm perception and reading comprehension skills in adult skilled readers. In addition, because previous studies have been conducted using behavioral measures, and often an explicit task directly focused on the prosodic aspects of the stimuli, it remains unclear to what extent the results of these experiments reflect individual differences in speech rhythm sensitivity (i.e., automatic, unconscious processing of the rhythmic cues) vs. speech rhythm awareness (i.e., explicit, conscious knowledge of the rhythmic structure of the language). The design of the present experiment used a combination of event-related potential (ERP) and behavioral measures that allowed examination of both sensitivity to and awareness of speech rhythm cues.

Research Questions, Design and Hypotheses

The study sought to address two research questions: (1) Can speech rhythm sensitivity and speech rhythm awareness be measured separately?, and (2) Are individual differences in speech rhythm sensitivity and/or awareness significantly associated with reading skills?

To address these questions, a revised version of the DEEdee task used by Whalley and Hansen (2006) was developed. Participants were presented with written bisyllabic words followed by two spoken bisyllabic phrases in which all syllables were replaced by the syllable "dee." Half of the written words had a trochaic stress pattern (i.e., stressed first syllable and unstressed second syllable, such as *apple*), while the other half had an iambic pattern (i.e., unstressed first syllable and stressed second syllable, such as *guitar*). One of the two "deedee" phrases that follow the written word was pronounced with a trochaic stress pattern while the other "deedee" phrase was pronounced with an iambic pattern. In addition, the order of presentation of the trochaic and iambic "deedee" versions was counterbalanced across trials. Participants were requested to decide which one of the two "deedee" phrases best matched the stress pattern of the written word. ERPs were measured using electroencephalography (EEG) recorded while participants listened to the "deedee" phrases. Behavioral performances on the DEEdee task provided a measure of the participants' speech rhythm awareness while ERPs measured during the listening of the "deedee" phrases were used as a measure of the participants' sensitivity to speech rhythm. Scores on the reading and English subsets of the American College Testing (ACT) were collected in order to be used as a measure of the participants' reading competence. Correlations between the behavioral data and ERPs collected from the revised DEEdee task and the ACT English and reading scores were analyzed to determine the relationship between participants' sensitivity and awareness to speech rhythm at the word level and their reading competence.

Regarding research question (1), a number of ERP studies on rhythm sensitivity in spoken language have observed an increased negative component using manipulations of speech rhythm, such as words with incorrect or unexpected/incongruent stress patterns (Böcker, Bastiaansen, Vroomen, Brunia, & de Gelder, 1999; Bohn, Knaus, Wiese, & Domahs, 2013; Domahs, Wiese, Bornkessel-Schlesewsky, & Schlesewsky, 2008; Magne et al., 2007; Magne, Jordan, & Gordon, 2016; Marie, Magne, & Besson, 2011; McCauley, Hestvik, & Vogel, 2012; Moon & Magne, 2015; Rothermich, Schmidt-Kassow, Schwartze, & Kotz, 2010). In line with these previous ERP studies on speech rhythm processing, it was hypothesized that "deedee" phrases spoken with a stress pattern that mismatches the written word would elicit an increased negative ERP component over frontal regions of the scalp if participants showed sensitivity to the lexical stress pattern of the prime written words.

Regarding research question (2), it was hypothesized that a significant relationship between participants' ACT English/reading scores and individual differences in ERP effects to mismatching "deedee" phrases would be found if sensitivity to speech rhythm contributed to reading comprehension. Likewise, if speech rhythm awareness contributes to reading ability, significant correlations were expected between performances on the DEEdee task and ACT English/reading scores. Because previous studies on the link between speech rhythm sensitivity and reading skills used behavioral measures (thus measuring mainly speech rhythm awareness), it was of interest to examine to what extent speech rhythm sensitivity measured with the ERP method correlated with speech rhythm awareness measured from the behavioral performances on the DEEdee task.

Significance of the Study

As stated previously, one of the most widely studied components of reading development has been phonological awareness. The focus has been primarily on the segmental aspects of phonology. However, an increasing body of evidence highlights the potential role of suprasegmental phonology (i.e., prosody) in reading skills. Therefore, the proposed study has potential theoretical implication for models of reading.

Finally, the use of an online neurophysiological measure (i.e., EEG) in combination with a behavioral measure can allow a better understanding of the neural mechanisms underlying prosody sensitivity. Recent studies indeed suggest that some of these neurophysiological markers have the potential to be used as diagnostic or progress monitoring tools (e.g., Lemons et al., 2010).

CHAPTER TWO

LITERATURE REVIEW

The literature reviewed in the present chapter focuses on three central areas of the current project: (1) the phonetic and phonological features of speech rhythm in English and their roles in language development and comprehension, (2) the various methodological approaches that have been taken to study speech rhythm sensitivity, including the rhythm perception measures that have been developed and the Event-Related Potentials (ERPs), and (3) the findings from previous research using these methods.

Lexical and Metrical Stress in English

There is strong evidence that stress patterns are an essential part of the phonological representation of words in English (Cutler, 1984). There are no general rules governing how stress patterns are assigned to every single word, which is why English is often considered a language with variable stress. Consequently, speakers must learn the stress placement for each word (Cutler, 1984). Slowiaczek, Soltano, and Bernstein (2006) pointed out a noteworthy distinction between lexical stress and metrical stress. According to their definitions of the two terms, lexical stress is the pattern of emphasis linked to the citation form of words, while metrical stress is defined as a conceptualization of stress. While metrical stress occurs across a phrase or a few syllables as a rhythmic pattern, lexical stress occurs in a word as a specific kind of metrical stress (Goodman et al., 2010).

In the present study, the term ‘stress’ was used to denote word-level prominence. This definition of stress aligns both with Cutler’s definition of stress

(1984) and with Fox's (2000) level 1 accentuation. Cutler (1984) distinguished between stress, which is used as a property of words, and accent, which is used as a property of sentences. On the other hand, Fox (2000) proposed a simple conceptual structure including two levels: level 1 accentuation (word stress) and level 2 accentuation (sentence stress).

Phonetic and Phonological Properties. In English, lexical stress is the main prosodic feature present in a word (Jusczyk, Cutler, & Redanz, 1993). English is often classified as a stress-timed language, which is characterized by whether or not a given syllable is stressed (e.g., Holliman et al., 2008). Accordingly, there are two kinds of syllables: strong syllables which receive stress and have a fully pronounced vowel, and weak syllables that are unstressed and often include a reduced vowel (Jusczyk et al., 1993). In the English vocabulary, stress patterns are not equally distributed (Jusczyk et al., 1993). According to Cutler and Carter (1987), less than 20% of English words, excluding function words, are weak-initial polysyllabic lexical words, while most common English words are bisyllabic words with a stressed initial syllable and an unstressed second syllable (Carlson, Elenius, Granstrom, & Hunnicutt, 1985). Similarly, about 90% of 190,000 words in a corpus are found to begin with strong stressed syllables (Cutler & Carter, 1987).

From a phonetic point of view, stress in a word has been described in terms of its acoustic and auditory features rather than with its physiological cause (Fox, 2000). This likely results from acoustic and auditory properties being far more accessible to researchers than physiological properties. Research has revealed that stressed syllables in an English word usually show similar variations of the physical characteristics of the acoustic signal: longer duration, higher frequency, and larger intensity than other unstressed syllables in a word (Slowiaczek et al., 2006). From the listener's point of view these characteristics provide perceptual cues (e.g., duration, loudness, and pitch) that are important for the identification of stressed syllables (Fox, 2000).

Linguists have proposed several phonological theories to explain stress patterns in terms of discrete units and hierarchical analysis of utterances (e.g., Liberman & Prince, 1977; Nespor & Vogel, 1986; Selkirk, 1986). For instance, Liberman and Prince (1977) proposed that the prosodic structure of a sentence can be represented using a phonological tree in which the branches below the word level can explain the relationships between syllable relative prominences. In languages with variable stress, such as English, polysyllabic words have one marked syllable with a higher degree of emphasis. The stressed syllable and any following unstressed syllables compose a basic accentual unit called the foot. In turn, one or several feet may compose a prosodic word (e.g., Selkirk, 1986). Beyond the prosodic word level, most phonological theories seek to define larger phonological units (e.g., phonological phrase, accentual phrase), though their definition and quantity remain a matter of debate (Beckman & Pierrehumbert, 1986; Selkirk, 1986). The present study focused on the prosodic word level and more specifically on sensitivity to and awareness of the foot structure of English bisyllabic words.

Roles of Speech Rhythm in Language Development and Comprehension. Previous research has indicated that speech rhythm sensitivity contributes to language acquisition from the early stage of life. For instance, Nazzi, Bertoncini, and Mehler

(1998) showed that newborns can distinguish between utterances from their mother tongue and those from a foreign language with a distinctive rhythm, but they cannot distinguish between utterances from their native language and those from a foreign language with a similar rhythm. These findings suggested that from birth, young infants have general auditory processing mechanisms allowing them to be sensitive to speech rhythm. Nazzi and Ramus (2003) reviewed several experiments conducted in infants between birth and 5-months-old. Findings confirmed that infants can discriminate between different languages based on prosodic cues during that timeframe of development. In addition, studies conducted with English speaking infants revealed that a preference for words with the frequent strong-weak stress patterns (compared to the less frequent weak-strong stress patterns) emerges around the age of 6 to 9 months, allowing language learners to use a metrical segmentation strategy of the continuous speech signal (Jusczyk et al., 1993).

Several research studies have attempted to establish whether lexical stress information is also utilized during word recognition in adult listeners. For instance, Cutler and Clifton (1985) examined mis-stressing effects on performances in a lexical decision task including English pseudowords and real words that were either correctly or incorrectly stressed on the first (trochaic) or second (iambic) syllable. Results showed that incorrect stress patterns significantly interfered with word recognition, especially if mis-stressing affected the vowel quality of the syllables. Similarly, Bond and Small (1983) found that mis-stressing was more detrimental to word recognition when vowel quality was also affected. On the other hand, prior-knowledge of the lexical stress pattern of the upcoming words did not appear to speed-up lexical decision making, suggesting that while information about stress patterns contribute to word recognition, its presence may not be a required condition to successfully recall a word from the lexicon (Cutler and Clifton, 1985).

Neurophysiological Indices of Stress Sensitivity. Since the 1960's, the ERP technique has been one of the most widely used tools by cognitive neuroscientists to measure brain electrical activity during perception and cognitive tasks (Woodman, 2010). ERPs are measured with Electroencephalography (EEG) using electrodes located on the participant's scalp and linked to an amplifier. Each peak and valley in the ERPs, also known as ERP components, are very small changes in voltage generated in the brain and they correspond to brain activity that is time-locked to sensory, motor, or cognitive processes (Blackwood & Muir, 1990).

According to Luck (2005), the ERP technique offers two main advantages. ERPs are useful for determining which step or steps of processing are influenced by a given experimental operation because they can continuously measure the process between a stimulus and a behavioral response. The other advantage is that ERPs can monitor online processing of information even in the absence of an overt behavioral response. On the other hand, one of the disadvantages of this methodology is that a large number of trials is required to measure ERPs properly. In addition, it is not possible to know the specific biophysical events underlying a given ERP response, making it difficult to interpret the functional significance of a given ERP component. Luck (2005) also compared the ERP technique to other brain imaging methods such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) along four dimensions: intrusiveness, spatial resolution, temporal resolution, and cost. The amount of fMRI or ERP data collected from an individual is theoretically not restricted, whereas PET experiments are problematic in terms of intrusiveness, since it necessitates the use of a radioactive tracer. Regarding the temporal resolution, ERPs have a one millisecond or better temporal resolution under ideal conditions, while PET and fMRI measures have limited resolution of several seconds. By contrast, compared to PET and fMRI, the spatial resolution of ERP is low, as the ERP components recorded from each electrode on the scalp reflect the summed contributions from many different generator sources. Finally, ERP experiments cost much less compared to PET and fMRI which are extremely expensive both in terms of equipment cost and operation.

Language-related ERP components. One of the most prominent ERP components in the field of language processing is the N400. First reported by Kutas and Hillyard (1980), the N400 is a negative wave that was found to be elicited by words that were unexpected in the semantic context of a sentence between approximately 300 and 600 ms following the word onset. Since then, the N400 has been shown to be elicited by any content word, regardless of whether they are heard or read, and its size is inversely related to the expectancy of a given word in the context in which it occurs (Luck, 2005). Analysis of neural sources shows the N400 to be generated mainly in the left temporal lobe (Luck, 2005), though it is often found to be slightly right-lateralized over the centro-parietal region of the scalp in reading experiments (Hwang & Steinhauer, 2011).

Another well-studied ERP component related to language is the P600, occurring from approximately 500-1000 ms post word onset in response to syntactic incongruities, syntactically ambiguous words, or syntactically complex structures (e.g., Friederici, 2002; Kaan & Swaab, 2003; Osterhout & Holcomb, 1992). It usually appears at centro-parietal sites. Its specificity to syntax has since been called into question, as similar P600 components have been found linked to other types of linguistic, as well as non-linguistic, manipulations. For instance, Kim and Osterhout (2005) found a P600 effect in response to semantic incongruities. In addition, some studies observed P600 elicited in response to prosodic violations (Astésano, Besson, & Alter, 2004; Magne et al., 2007; Marie et al., 2011).

ERPs and prosody sensitivity. Another positive component has been found to be elicited at the boundaries of intonational phrases in speech (Steinhauer, Alter, & Friederici, 1999). Named the closure positive shift (CPS), this positivity is usually observed later than the P600 and is also more sustained over time. The CPS does not seem to be specific to a given language as it has been reported in German (Pannekamp, Toepel, Alter, Hahne, & Friederici, 2005; Steinhauer et al., 1999), Swedish (Roll & Horne, 2011), Japanese (Wolff, Schlesewsky, Hirotani, & Bornkessel-Schlesewsky, 2008), and Korean (Hwang & Steinhauer, 2011).

Regarding speech rhythm perception, ERP studies have used a diversity of manipulations, such as words with incorrect lexical/metrical stress patterns (Domahs et al., 2008; Magne et al., 2007; Marie et al., 2011; McCauley et al., 2012), words with correct but unexpected stress patterns (Böcker et al., 1999; Bohn et al., 2013; Magne et al., 2016; Moon & Magne, 2015), or unexpected stress patterns in meaningless words such as pseudowords (Rothermich et al., 2010). Languages investigated by researchers have also varied across studies: French (Magne et al, 2007; Marie et al., 2011), English (Magne et al., 2016), Dutch (Böcker et al., 1999), and German (Domahs et al., 2008; Rothermich et al., 2010; Schmidt-Kassow & Kotz, 2009). Furthermore, the tasks performed by the participants during the experiments were also variable. For instance, some studies included a task explicitly focused on word stress (Bohn et al., 2013; Domahs et al., 2008) or pronunciation (McCauley et al., 2012), whereas others used distractor tasks aimed at focusing the participants' attention away from the prosodic aspect of the stimuli (e.g., Magne et al., 2007; Marie et al, 2011; Rothermich, Schmidt-Kassow, & Kotz, 2012). Interestingly, even though the above-mentioned studies varied in terms of language, task, and linguistic manipulation, an early increased negative ERP was often observed in response to words with incongruent or unexpected stress patterns. Compared to the N400 component, this negativity is usually produced in an earlier latency range, between 200 and 400 ms, and its scalp distribution is more centro-frontal. This negativity has been interpreted as either reflecting a general error detection response (Rothermich et al., 2010) or an N400-like response reflecting the influence of prosodic information on lexico-semantic processes (Magne et al., 2007; Marie et al., 2011).

In some studies, this negative ERP effect is followed by a late positive wave occurring between 500 and 900 ms over centro-parietal areas of the scalp (e.g., Domahs et al., 2008; Magne et al., 2007; Marie et al., 2011; McCauley et al., 2012). Because this positivity shares many properties with the P600 component, and it is more often observed when the task is explicit (i.e., directed toward the prosodic aspects of the stimuli), it has been proposed to reflect cognitive processes that are more sensitive to the task than to the linguistic manipulation of the stimuli (Magne et al., 2007).

Developed Prosodic Measures

DEEdee Task. The present study used a revised version of the DEEdee task, initially developed by Kitzen (2001) to measure prosodic sensitivity at the phrase level. This task has been used with young adults (Kitzen, 2001) as well as with children (Clin et al., 2009; Goswami, Gerson, & Astruc, 2009; Holliman et al., 2012; Whalley & Hansen, 2006). In the DEEdee task, a prime stimulus (e.g., word or picture) is followed by two spoken phrases in which each syllable is replaced with the syllable "dee", with the purpose of removing phonetic information. One of the two "deedee" phrases matches the metrical stress and intonation of the prime stimulus while the other "deedee" phrase does not. Participants are asked to choose which one of the two "deedee" phrases matches the prime stimulus.

Several alternative versions have been used with varying numbers and types of stimuli. For instance, Kitzen (2001) changed film and story titles into "deedee" phrases. Specifically, *Casablanca* was converted into DEEdeeDEEdee (i.e., pronounced with a stressed-unstressed-stressed-unstressed syllable pattern). The participants heard taped-recorded "deedee" phrases while viewing three written word choices. Whalley and Hansen (2006) adapted the task from Kitzen's study (2001) by selecting titles of books, films, and television programs which were popular with children, such as *The Fox and the Hound* (deeDEEdeedeeDEE) and *Sesame Street* (DEEdeedeeDEE). In contrast to Kitzen (2001), the prime stimuli were spoken rather than written, and participants had to choose which one of the two "deedee" versions matched the prime spoken phrase. The same DEEdee task was used by Holliman et al.

(2012) and Clin et al. (2009). Goswami et al. (2009) used pictures rather than words as prime stimuli and included famous names such as “David Beckham” (a soccer player), as well as film and book titles similar to those used by Whalley and Hansen (2006). Another important difference is that Goswami et al. (2009) used synthesized versions of “dee” syllables to create “deedee” phrases, while Kitzen (2001) and Whalley and Hansen (2006) used “deedee” phrases naturally produced by an adult English speaker.

It should be noted that Holliman et al. (2012) reported poor internal reliability ($\alpha = .37$) for their DEEdee task, and Goswami et al. (2009) found a Cronbach’s alpha for their version lower than 0.50. The present study aimed to address this issue by using linguistic stimuli that were more consistent in terms of word length (only bisyllabic), word category (only nouns) and lexical frequency (only highly frequent words). In addition, synthesized versions of “deedee” phrases were used rather than natural recordings in order to have a consistent intonation, speaking rate, and stress realization.

Stress Mispronunciation Task. With the DEEdee task, the mispronunciation task has been the most commonly used measure in this emerging literature. The purpose of this task is to assess children’s sensitivity to changes in lexical stress patterns (Goodman et al., 2010; Holliman et al., 2008; 2010a; 2010b; 2012; Wood, 2006). Participants are presented with words that are systematically mispronounced (e.g., stressed on the second syllable instead of the first syllable) and are asked to choose the correct object among different items located in a cartoon drawing of a house (e.g., Goodman et al., 2010; Holliman et al., 2008). The underlying assumption is that children with better speech rhythm sensitivity should be able to notice that the word stress pattern has been reversed and are able to mentally correct it to accomplish the task. In one study, the mispronunciation task was found to have an acceptable internal reliability with a Cronbach's alpha equal to .79 (Holliman et al., 2008).

Holliman et al. (2010a, 2010b, 2012) developed a revised version of the stress mispronunciation task in which participants listened to a word spoken with a reversed stress pattern, and they had to choose the correct object among a selection of four pictures. Compared to the previous version of the task, the distractor objects shared the same initial phoneme as the target spoken word and were matched in terms of word frequency to control for the potential influences of phonemic awareness and vocabulary. However, Cronbach's alpha reliability coefficients for this revised version were mixed: internal reliability was acceptable in two studies (Holliman et al., 2010a, $\alpha = .81$; Holliman et al., 2010b; $\alpha = .82$) but poor in another (Holliman et al., 2012, $\alpha = .37$).

Compound Nouns Task. This task was first developed for assessing children's prosodic sensitivity at the word level (Wells & Peppe, 2003), and later revised by Whalley and Hansen (2006) to include two tasks with different stimuli. Task A juxtaposed a noun phrase with the structure of a three-noun sequence, such as *foot, ball, and socks* with a noun phrase consisting of a compound noun created by the first two nouns followed by the third noun (i.e., *football and socks*). Task B juxtaposed noun phrases consisting of an adjective and a noun (e.g., *high chair*) with noun phrases consisting of a compound noun derived by those two words (i.e., *highchair*) embedded in carrier sentences (e.g., *The highchair is in the corner*).

Children were asked to choose the picture on an answer sheet that best matched the spoken phrase. The underlying assumption is that children with better prosodic sensitivity should be able to identify the prosodic differences between compound nouns and noun phrases based on the intonation, lexical stress, and pauses. One of the main advantages of this task is that it can be performed without having to consciously focus the participants' attention toward the prosodic properties of the linguistic stimuli (Wade-Wooley & Heggie, 2016).

Beat Detection Task. Goswami et al. (2002) developed a beat detection task to explore rhythm perception skills in individuals with dyslexia. Compared to the tasks previously described, the beat detection task does not directly measure prosody sensitivity, but rather general auditory temporal processing skills that are thought to be necessary for perceiving the phonetic correlates of speech rhythm. The beat detection task uses non-speech sounds manipulated in terms of the rate of change of their amplitude modulation (i.e., envelop rise time). Rise time has been proposed to be one of the cues in the envelop of the speech signal that is important to identify stressed syllables (Goswami et al., 2009). This task includes sounds with a rise time varying along a continuum between 15 and 300 ms. Participants are usually first trained using only the two extreme rise time versions (15 and 300 ms) and are asked to associate them to two cartoon characters. Then, during the testing phase, participants are presented with sounds varying along the continuum and asked to decide to which character each sound belongs. Internal reliability measures were not reported for this task.

Metrical Stress Sensitivity and Reading Skills

Rhythm Perception and Reading Acquisition. Since sensitivity to rhythm cues appears to contribute to speech segmentation and spoken word recognition early during language development, several studies have also examined to what extent awareness of these speech rhythm cues affect the development of phonological awareness and other reading-related skills using the tasks reviewed in the previous section. Wood and Terrell (1998) measured metrical stress sensitivity in thirty primary children who were identified as poor readers. They used a rhythm-matching task to examine whether metrical stress sensitivity contributed to reading skills, including word recognition and phonological awareness. During the rhythmic matching task, participants were asked to identify which of two spoken sentences was pronounced with the specific stress pattern arrangement (e.g. SWWSSS or SWWSWS). Results revealed that readers with limited reading ability performed significantly more poorly than the reading-age-matched control group. Wood and Terrell proposed that better metrical stress sensitivity might help children pay attention to stressed syllables, leading them to recognize phonemes more easily in stressed syllables therefore facilitating the development of phonemic awareness. Using the mispronunciation task, Wood (2006) also found a significant relationship between five to seven-year-old children's lexical stress sensitivity and their spelling skills, even after controlling for phonological awareness and vocabulary. Whalley and Hansen (2006) examined metrical stress sensitivity at the phrase level using two tasks, the compound nouns task, and the DEEdee task. They found that participants' scores on the DEEdee task predicted a significant amount of variance in reading comprehension while their performance on the compound nouns task predicted a significant amount of variance in word identification. Holliman et al. (2008) measured stress sensitivity of five to six-year-old English-speaking children using the stress mispronunciation task and showed that participants' performance on this task predicted a significant amount of variance in reading achievement, even after controlling for age, vocabulary, and phonological processing skills. Using a revised version of the mispronunciation task, Holliman et al. (2010a) found that speech rhythm sensitivity was a significant predictor of word reading accuracy and reading fluency measured one year later, even after controlling for age, phonological awareness, and vocabulary.

It is important to note that not all studies found a significant relationship between speech rhythm sensitivity and reading. Investigating more precisely the unique contribution of lexical stress and metrical stress, Goodman et al. (2010) found that preschoolers' sensitivity to lexical stress, but not metrical stress, was significantly associated with their reading achievement and phonological awareness. In addition, results showed that lexical stress sensitivity did not predict a significant amount of variance in young children's reading achievement after controlling for phonological awareness. Similarly, Beattie and Manis (2014) examined preschool children's sensitivity to lexical stress using repetition tasks involving pseudowords and syllables with various stress patterns. Children's performance on the speech rhythm tasks significantly accounted for variance in phonological awareness but not after controlling for receptive vocabulary. However, the authors argued that sensitivity to speech rhythm may still contribute indirectly to the development of phonological awareness by facilitating the acquisition of receptive vocabulary.

In sum, many studies provide evidence that speech rhythm perception skills support the early development of good reading skills. However, results are not always replicated and sometimes diverge in terms of which reading component is particularly influenced by sensitivity to prosody. In addition, studies vary in terms of task demands, making it difficult to distinguish between the effects of prosodic sensitivity (i.e., automatic, unconscious use of prosodic information) and prosodic awareness (i.e., conscious manipulation of prosodic information). Differentiating between the effects of prosodic awareness and prosodic sensitivity on reading comprehension is thus one of the main goals of the present study.

Implicit Prosody Hypothesis. Several previous studies also examined the role of metrical stress sensitivity while adults read silently (Ashby, 2006; Ashby & Clifton, 2005; Breen and Clifton, 2011; Magne, Gordon, & Midha, 2010; Wikenfield, 1985). In particular, they sought evidence that prosody plays a role during silent reading even when prosodic information is not explicitly provided by orthographic cues. This idea was initially conceptualized by Fodor (1998, 2002) in the Implicit Prosody Hypothesis (IPH). According to the IPH, prosodic representations, such as sentence intonation, phrasing, word stress, and rhythm, are engaged, even during silent reading, influencing the reader's interpretation of the text (Breen, 2014).

IPH is supported by results from eye-tracking studies conducted in adult skilled readers. For instance, Ashby and Clifton (2005) investigated the role of implicit metrical stress during silent reading using eye-tracking to determine whether the number of stressed syllables in four-syllable words would influence their reading time. Results showed longer reading times and more eye fixations for words containing two stressed syllables than words with only one stress. In a follow-up eye-tracking study, Ashby (2006) examined whether prosodic processing during silent reading differed for high and low frequency words. Participants read target words embedded in sentences while part of the target word was presented in the parafoveal region. All target words had an initial syllable with a consonant-vowel structure (e.g., “position”). The parafoveal partial word included either the first two letters of the target word, making it congruent with the target’s first syllable (e.g., “po”) or the first three letters of the target word, thus making it incongruent since it contained one more letter than the initial syllable (e.g., “pos”). The assumption was that if prosodic information is used during silent reading, target words should be read faster when presented with parafoveal information that is compatible with the initial syllable structure than when it is incompatible with it. Alternatively, if prosodic information is not used, reading time should be faster when the parafoveal information provides more letters about the target word. Results showed that participants’ reading times for the high frequency words were not significantly different between the congruent and incongruent parafoveal conditions. However, reading times for low frequency words were found to be faster in the congruent condition. Thus, these results implied that prosodic information is available early during word recognition and may be used even parafoveally to facilitate lexical access.

Findings from Breen and Clifton (2011) also showed that the metrical stress of a sentence can guide expectancies about upcoming words. Participants silently read limericks with a noun-adjective or noun-verb stress-alternating homograph at the end of the second line out of five lines. The first line of the limericks had a stress pattern that constrained the metrical structure of the second line. The metrical structure was either compatible or incompatible with the lexical stress pattern of the homograph ending the second line. The results from eye-tracking measurements showed longer reading times when the lexical stress of the homograph was incompatible with the expectations set by the metrical structure of the limericks, further supporting the idea that information about metrical and lexical stress is used during silent reading.

There is also neurophysiological evidence for processing of implicit speech rhythm. In an ERP study by Magne et al. (2010), participants silently read sets of five bisyllabic words in which the last word had the same or opposite stress pattern compared to the first four of the set. All words within each set were controlled for lexical frequency. They observed that final words with the opposite stress pattern elicited an increased N400 component which was interpreted as reflecting an increased load on access to semantic memory (Kutas & Federmeier, 2011). These results strongly suggested that stress patterns in a word are implicitly and automatically processed and influence word recognition during silent reading (Magne et al., 2010).

In summary, studies using eye-tracking measurements and EEG methodologies provide evidence in favor of the view that prosodic information is automatically activated during silently reading, though the extent to which this information might affect reading comprehension remains to be further explored.

Rhythm Perception Skills and Reading Disorders. In addition to examining the role of metrical stress sensitivity during reading acquisition, there have been many studies comparing metrical stress sensitivity between children with reading disorders, often dyslexia, and a control group matched for reading level and/or age (de Bree, Wijnen, & Zonneveld, 2006; Goswami et al, 2002; 2009; Kitzen, 2001; Leong, Hämäläinen, Soltész, & Goswami, 2011; Richardson, Thompson, Scott, & Goswami, 2004; van Alphen, de Bree, Fikkert, & Wijnen, 2007). For instance, de Bree et al. (2006) compared production of Dutch word stress between three-year-old children at risk for dyslexia and age-matched controls, using a repetition task including pseudowords varying in terms of stress pattern regularity (from highly regular to unacceptable stress pattern in the language). While the children at risk and the controls performed similarly on the regular stress patterns, children at risk performed worse than children in the control group on the irregular and unacceptable stress patterns. In a follow-up study, van Alphen et al. (2007) collected data from three-year-old children at risk for dyslexia and typically developing children to assess the role of metrical stress in production and comprehension. They used the same stress production task as de Bree et al. (2006) as well as a picture identification task in which two pictures were presented on two screens followed by a spoken sentence containing the name of one of the two pictures. In addition, picture names were pronounced with either a correct or incorrect stress pattern. The face of the children was videotaped to determine which pictures they looked at and the number of eye fixations during the presentation of the spoken sentences. In line with de Bree et al., (2006), their findings revealed that children at risk again performed at the same level as control on the repetition task when pseudowords had a regular stress pattern. However, only children in the control condition showed a significant difference in number of eye fixations between target pictures correctly stressed vs. incorrectly stressed, suggesting that children at risk are less sensitive to stress mismatches. The authors proposed that while representations of word stress patterns may not be impaired in children at risk (as suggested by the production task), they do not seem to exploit metrical stress information to guide their word recognition (as suggested by the results of the picture identification task).

Goswami et al. (2002) developed a beat detection task to examine more basic auditory rhythm perception skills, using non-speech auditory sequences. Compared to age-matched and reading level-matched controls, children with dyslexia were significantly impaired on the beat detection task (Goswami et al., 2002). Not only was beat detection found to be strongly associated with reading and spelling, but it was also significantly related to individual differences in phonological processing. Even after controlling for phonological processing, beat detection was a significant predictor of literacy outcomes. In a follow-up study, Goswami et al. (2009) examined whether sensitivity to rise time was associated to prosodic sensitivity (measured using the DEEdee task) and phonological awareness. They developed a battery of tasks comprising three rise time measures, a frequency sensitivity measure, and an intensity sensitivity measure to examine various aspects of the amplitude envelop structure. All the auditory tasks were administered using a software program in which children were asked to decide which dinosaur cartoon character sound showed the target auditory feature after five practice trials. The findings indicated that the dyslexic children's sensitivity to prosodic information was related to impaired auditory and phonological processing skills.

Finally, Kitzen (2001) and Leong et al. (2011) focused their study on metrical stress perception in adults with dyslexia using the DEEdee task. Kitzen (2001) found that young adults with dyslexia performed much poorer on the DEEdee task than age-matched controls. In line with this finding, Leong et al. (2011) also found that participants with developmental dyslexia achieved significantly less than their control peers on the stress perception task. Leong and her colleagues indicated that sensitivity to prosodic processing measured using the stress perception task was significantly associated with individual differences in phonological reading and spelling skills.

In sum, several studies conducted on individuals with reading disorders suggest a strong link between rhythm processing skills and reading abilities. In addition, the findings suggest that lower rhythm perception skill is not specific to language and may result from a more basic auditory rhythm processing deficit.

CHAPTER THREE

METHOD

Participants

A total of twenty-four college students at a southeastern university was recruited for the present study. All the participants were native speakers of English, with no known history of neurological and psychiatric disorders, without known hearing and vision deficits and all were right-handed. Two participants were excluded because their EEG data were contaminated by too many artifacts (e.g. eye movements, blinks, amplifier saturation, or muscle activity). Consequently, twenty-two young adults were included in the analyses (Mean of age = 18.5). There were 14 females and 8 males. All participants received course credits for participation in the experiments. The present study was approved by the Institutional Review Board (IRB) Committee at Middle Tennessee State University (MTSU). Written informed consents were obtained from participants before starting the experiment (see Appendix C for copies of the consent form and the IRB approval letter).

Standardized Measure of Reading

Participants' American College Testing (ACT) score on the English and reading subtests were collected as a measure of their reading skills. The ACT is a standardized test measuring high school achievement and academic readiness for college in the United States. The ACT is composed of four multiple-choice subject subtests: English, mathematics, reading, and science reasoning. The English section is a 45-minute test that includes five passages. A total of 75 questions covers English grammar, usage and mechanics, sentence structure, strategy, organization, and style.

The reading section includes four passages from the fields of prose fiction, humanities, social science, and natural science. Students are given ten comprehension questions for each passage. The reading subtest is 35 minutes long. For both the English and reading sections, the raw score corresponds to the number of correct answers. The raw score is then converted into a scale score ranging from 1 (low) to 36 (high).

EEG DEEdee Task

The DEEdee task used by Whalley and Hansen (2006) was modified for the present study. This task was selected because the performance of the participants was found to be significantly associated with word reading (e.g., Goswami et al., 2009; Whalley & Hansen, 2006). Whalley and Hansen (2006) used 18 written phrases taken from titles of books, films, and television programs, such as *The Fox and the Hound* (deeDEEdeedeeDEE). However, these phrases systematically varied in term of word stress pattern, part of speech (e.g., noun, adjective, verb), and number of words which may account for some of the discrepancy found across studies using the DEEdee task. To address these potential confounds, only isolated bisyllabic nouns were used in the present study. In addition, half of the words were stressed on the first syllable (i.e., trochaic pattern), while the other half were stressed on the second syllable (i.e., iambic pattern).

A total of 140 common nouns (70 iambic and 70 trochaic) were selected from the English Lexicon Project database (Balota et al., 2007; see Appendix B for a complete list of the stimuli). Because the trochaic stress pattern is inherently more common than the iambic pattern in English (Cutler & Carter, 1987), the lexical frequency of trochaic and iambic words was controlled for using the log HAL frequency (Lund & Burgess, 1996). The mean frequency was 10.29 (SD = 0.98) for trochaic words and 10.29 (SD = 0.98) for iambic words. The mean word length was 5.86 letters (SD = 0.9) for trochaic words and 6.44 letters (SD = 0.98) for iambic words.

Two “deedee” words were spoken by a female voice at a sampling rate of 44 kHz using the Neospeech Text-to-Speech software (Neospeech, Inc., Santa Clara, CA). One of the two “deedee” words was pronounced with a stress on the first syllable, while the other “deedee” word was stressed on the second syllable. Artificial rather natural voice was used in order to have a consistent speech rate and intonation across the two “deedee” versions.

The differences in phonetic properties between the trochaic and iambic "deedee" versions were analyzed using Praat 5.4 (Boersma & Weenink, 2007). First, the acoustic onset and offset of the first and second syllables were manually detected for each "deedee" word. Then, the duration, maximum pitch (f0) and intensity (dB) values were extracted for each syllable (see Table 1 below).

Table 1

Acoustic analysis of the "deedee" words

	Trochaic Deedee			**Iambic Deedee**		
	1st Syllable	2nd Syllable	D	1st Syllable	2nd Syllable	D
Duration (ms)	298	283	15	216	363	-147
Intensity (dB)	80	75	5	77	75	2
Pitch (Hz)	235	170	65	190	196	-6

Note. D = Difference between the first and second syllables.

For each trial, participants were presented with a written word followed by a pair of "deedee" words including an iambic version and a trochaic version. The presentation order of the two "deedee" words was pseudo-randomized so that for half of the trials, the "deedee" that matches the stress pattern of the prime written word was presented first. Four conditions were created by manipulating the location of the stressed syllable in the prime written word (trochaic vs. iambic) and the order of presentation of the two types of "deedee" words (trochaic "deedee" first vs. iambic "deedee" first): (1) first "deedee" word matched with trochaic word, (2) first "deedee" word matched with iambic word, (3) first "deedee" word mismatched with trochaic word, and (4) first "deedee" word mismatched with iambic word (see Table 2 for examples of stimuli).

Table 2

Examples of stimuli in each condition

Written Words	Deedee Words	Examples
Trochaic Word	Matched	Apple - DEEdee, deeDEE
Trochaic Word	Mismatched	Number - deeDEE, DEEdee
Iambic word	Matched	Guitar - deeDEE, DEEdee
Iambic word	Mismatched	Degree - DEEdee, deeDEE

Note. The stressed syllable in the “deedee” word is indicated in capital letters.

Procedure

Participants were comfortably seated in a sound-proof room facing a computer screen. During the experiment, they read written words on a computer screen and listened to pairs of “deedee” words via headphones. Participants were asked to decide which “deedee” word of the pair matched the stress pattern of the written word. Stimuli were presented using the software E-prime 2.0 Professional with Network Timing Protocol (Psychology software tools, Inc., Pittsburgh, PA). Each trial began with the presentation of a fixation cross for 500 ms. Then, the written word was presented for 500 ms, followed by the audio of the first “deedee” word, a silence of 500 ms, and the audio of the second “deedee” word. After the second “deedee” word, a visual cue (Which one matches? 1 or 2?) remained on the screen until the participant gave an answer. In between trials, a series of X’s was displayed in the center of the screen to indicate to the participants when they could move their eyes or blink. Prior to the start of the experiment, participants performed a practice block consisting of 8 trials in order to familiarize themselves with the experimental procedure.

EEG Data Acquisition

Participants' EEG were recorded continuously from 128 Ag/AgCl electrodes embedded in sponges in a Hydrocel Geodesic Sensor Net (EGI, Eugene, OR, USA) and connected to a NetAmps 300 amplifier. The electrode net was placed on the scalp, with the electrode Cz placed at the vertex. Data were referenced online to Cz during the recording and later rereferenced offline to the average of the left and right mastoid electrodes. The frequency of acquisition was 500 Hz, and impedances were kept below 50 kOhms. EEG preprocessing was performed using NetStation 4.5 Viewer and Waveform tools (EGI, Eugene, OR, USA). The vertical and horizontal electrooculograms (EOG) were also recorded in order to detect eye blinks as well as eye movements. The EEG data were filtered offline with a bandpass of 0.1 to 100 Hz. ERPs were then computed for each electrode by averaging together the artifact-free EEG segments, separately for each condition and each participant.

Data Analysis

Behavioral data for trochaic vs. iambic words were compared using a two-sample t-test on the number of correct responses (i.e., accuracy rates) and reaction times (in milliseconds). EEG data were analyzed using the cluster-based permutation approach implemented in the Matlab toolbox Fieldtrip (Oostenveld, Fries, Maris, & Schoffelen, 2011) in order to investigate the cross-modal priming effect of the stress pattern of the prime written word on the perception of the first "deedee" word of the spoken pseudoword pair. In addition, because trochaic and iambic stress patterns have different frequencies of occurrence (Cutler & Carter, 1987) as well as different developmental trajectories (Jusczyk, 1999) in English, planned comparisons between the matching condition (i.e., the stress pattern of the first “deedee” word matches the written word) and the mismatching condition (i.e., the stress pattern of the first “deedee” word mismatches the written word) were conducted separately for each type of stress pattern.

In order to examine the relationship between metrical stress sensitivity and reading comprehension, a correlation matrix was computed using the participants’ ACT English/reading scores and their indices of trochaic and iambic stress sensitivity calculated from the ERP effects. These ERP indices were computed using the cluster sum approach developed by Lense, Gordon, Key, and Dykens (2014) on each significant cluster identified by the cluster-based permutation procedure. First, the sum of the ERP amplitudes at each electrode part of the significant cluster was computed separately for each condition. Then, the ERP index of trochaic stress pattern sensitivity was defined as the summed cluster value obtained for the trochaic mismatch condition subtracted from the summed value for the trochaic match condition. Similarly, for the ERP index of iambic stress pattern sensitivity, the summed cluster values obtained for the iambic mismatch were subtracted from the summed value for the iambic match. All correlation analyses were performed in Matlab using the Statistics toolbox (The Mathworks, Natick, MA).

CHAPTER FOUR

RESULTS

Behavioral Data

Table 3 shows the mean and standard deviation for the accuracy rates on the DEEdee task. Overall, performance was relatively poor in both conditions, suggesting that the task was challenging for the participants. A one-sample *t*-test conducted on the overall accuracy rates showed that their mean (65%) was significantly different from 50%, the chance level for the two-alternative forced choice method used in the DEEdee task [$t(21) = 1587.85$, $p < 0.0001$, $d_z = 338.53$]. A paired *t*-test on the accuracy rates revealed significantly better performance for iambic prime words than trochaic prime words [$t(21) = -2.49$, $p < .05$, $d_z = 0.53$].

Table 3

Mean and standard deviation (SD) for the accuracy rates on the DEEdee task

Accuracy Rate (%)	Trochaic Prime	Iambic Prime
Mean	61	69
SD	16	16

In addition, Cronbach's alpha was calculated on the accuracy rates and indicated good internal consistency ($\alpha = .93$).

ERP Data

Cluster-based permutation tests were computed to evaluate the time range and scalp distribution of the differences between matching "deedee" words and mismatching "deedee" words. These analyses were done separately for trochaic prime words (i.e., matching trochaic "deedee" vs. mismatching iambic "deedee") and iambic prime words (i.e., matching iambic "deedee" vs. mismatching trochaic "deedee").

Trochaic Prime Words. Results showed that "deedee" words pronounced with a mismatching iambic stress pattern were associated with an increased early negativity between 232 and 358 ms post word onset (p = .0017), followed by a late negativity between 498 and 584 ms post word onset (p = .0073), when compared to matching trochaic "deedee" words (see Figure 1, bottom panel). Both negative ERP effects had a centro-frontal distribution on the scalp (see Figure 1, top panel).

Iambic Prime Words. Mismatching "deedee" words pronounced with a trochaic stress pattern elicited a larger late negativity than matching iambic "deedee" words between 378 and 454 ms post word onset (p = 0.049; see Figure 2, bottom panel). This negativity was significant over centro-frontal regions of the scalp, but distributed over a smaller subset of electrodes than the late negative ERP effect found for trochaic prime words (see Figure 2, top panel).

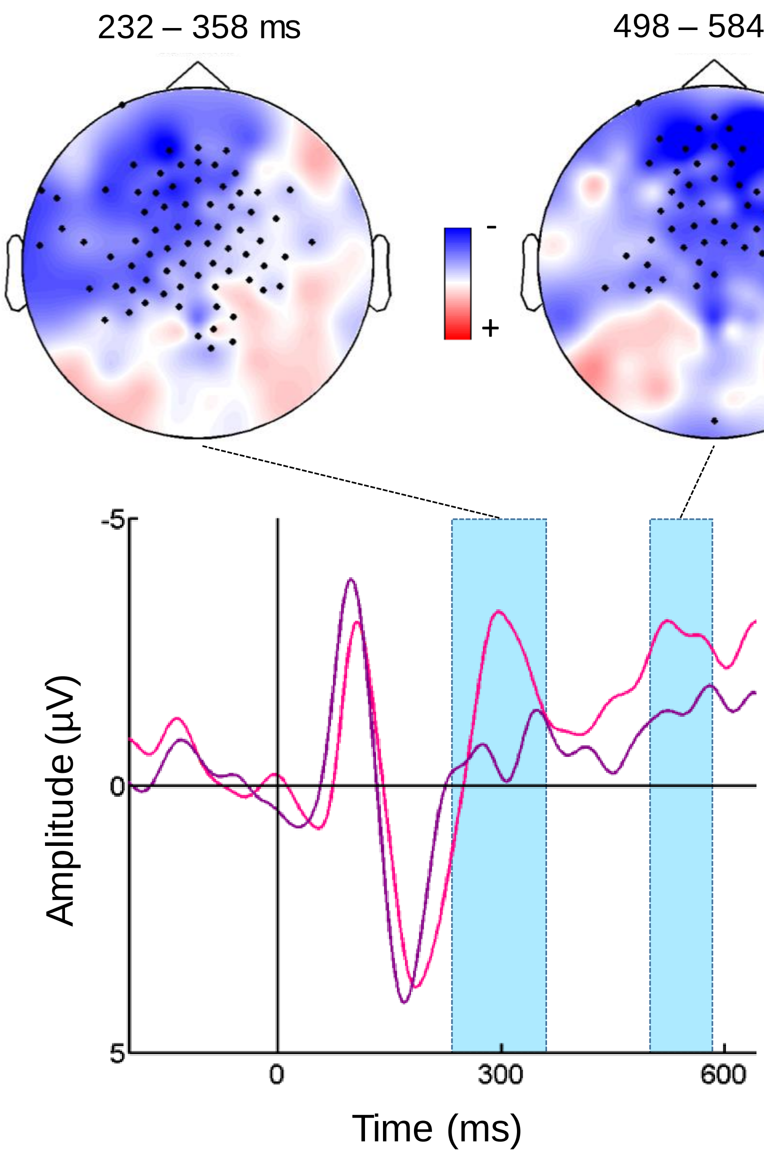

Figure 1. Trochaic prime effect. ERPs elicited by matching trochaic “deedee” (purple trace) and mismatching iambic “deedee” (pink trace) words following trochaic prime words (bottom panel). The latency ranges of the significant negative clusters are indicated by a blue rectangle. Topographic maps show the averaged amplitude difference between matching and mismatching “deedee” ERPs in the time range of the significant clusters (top panel). Electrodes included in the significant clusters are indicated by a black dot.

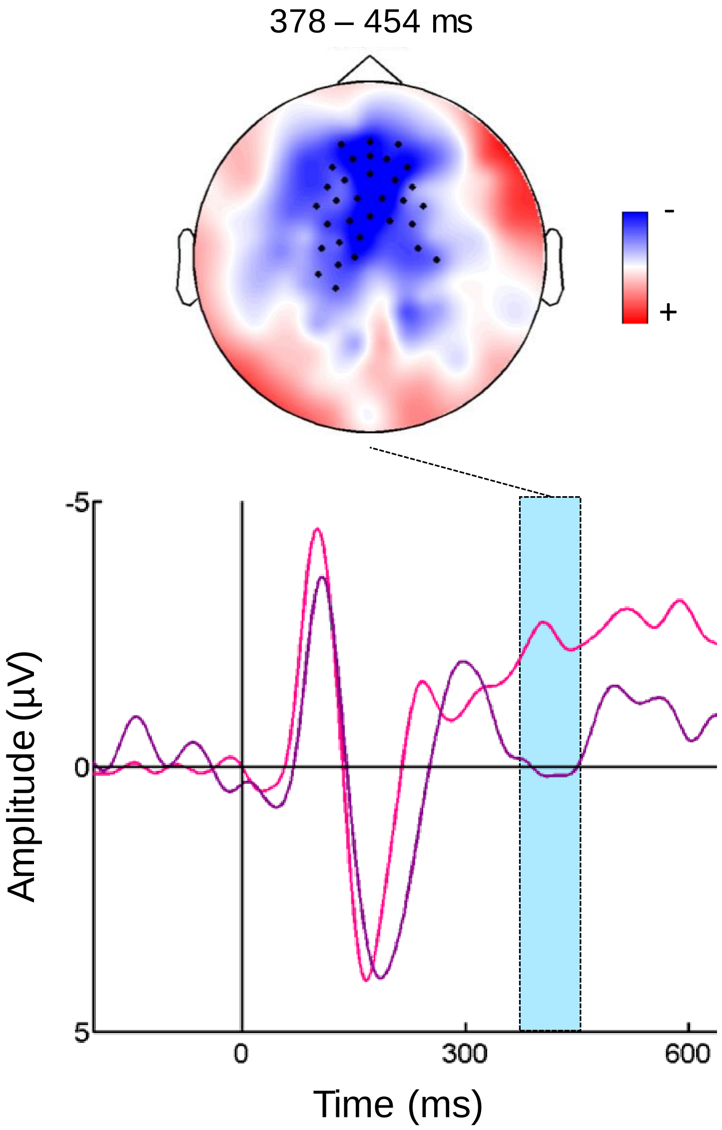

Figure 2. Iambic prime effect. ERPs elicited by matching iambic “deedee” (purple trace) and mismatching trochaic “deedee” (pink trace) words following iambic prime words (bottom panel). The latency range of the significant cluster is indicated by a blue rectangle. Topographic map shows the averaged amplitude difference between matching and mismatching “deedee” ERPs in the time range of the significant cluster (top panel). Electrodes included in the significant cluster are indicated by a black dot.

Intercorrelations among Speech Rhythm Awareness, Speech Rhythm Sensitivity, and Reading Skills

In order to examine how speech rhythm perception skills (i.e., sensitivity and awareness) are associated with reading skills, participants' ACT scores on the English and reading subtests were collected. Participants' average ACT scores were 21.09 (*SD* = 4.36) on the English subtest and 21.50 (*SD* = 5.52) on the reading subtest. Their average ACT scores were slightly higher than the national average for 2016 (*M* = 20.1 for the English subtest, and *M* = 21.3 for the reading subtest).

Speech Rhythm Awareness and Reading Skills. Correlations were calculated between ACT reading scores and accuracy rates for trochaic and iambic prime words on the DEEdee task. Since previous studies suggested that sensitivities to the trochaic and iambic stress patterns follow different developmental trajectories in English native speakers (e.g., Jusczyk et al., 1993), the difference between the accuracy rates for trochaic and iambic prime words was also calculated for each participant to examine the link between ACT scores and individual differences in awareness between these two types of stress pattern.

Results of the analyses revealed a significant moderate positive correlation between the ACT English scores and the accuracy rates for iambic prime words ($r = .56$, $p < .01$), suggesting that participants with better awareness of the iambic stress pattern are likely to have higher ACT English scores (see Figure 3a). There was also a significant moderate positive relationship between the ACT reading scores and the individual differences of accuracy rates between trochaic and iambic prime words (*r*

= .44, $p < .05$), implying that participants with better iambic than trochaic awareness were more likely to have higher ACT reading scores (see Figure 3b).

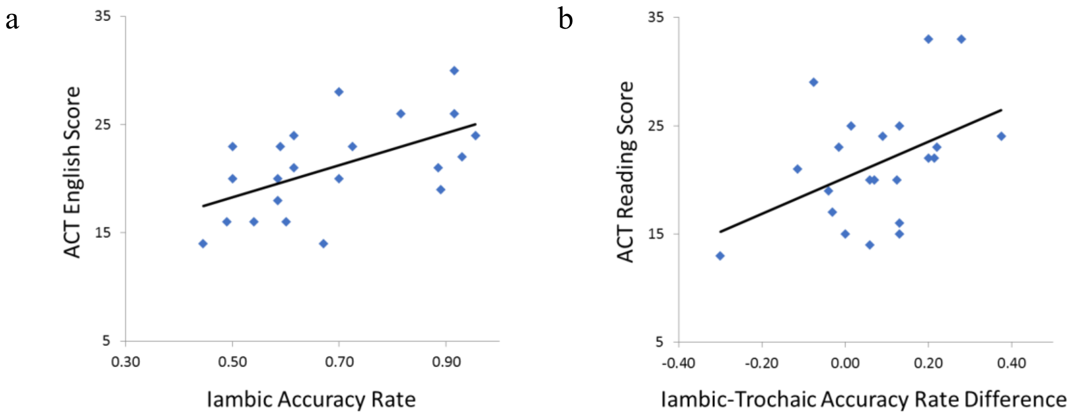

Figure 3. Relationship between reading skills and DEEdee task performances. Correlations between ACT English scores and accuracy rates for the iambic prime word condition (a), and between ACT reading scores and the accuracy rate differences between iambic and trochaic prime word conditions (b). The solid line represents a linear fit.

Speech Rhythm Sensitivity and Reading Skills. ERP cluster sum values were calculated using the procedure described in the method section and used as indices of speech rhythm sensitivity. ERP cluster sum values were calculated for the early and late negative clusters found for trochaic prime words and the late negative cluster found for the iambic prime words. Correlations were then computed between the ACT English/Reading scores and the ERP cluster sum values to examine whether or not there was any significant relationship between speech rhythm sensitivity and reading skills. Results of the analyses did not reveal any significant correlation between the ERP cluster sum values and any of the ACT scores.

Speech Rhythm Awareness and Speech Rhythm Sensitivity. In order to investigate the link between speech rhythm awareness and speech rhythm sensitivity, correlations were computed between the ERP cluster sum values and the participants' accuracy rates on the DEEdee task. They were calculated separately for the trochaic and iambic prime word conditions. Results revealed a significant moderate positive correlation between the amplitude of the early negative ERP effect produced by mismatching iambic "deedee" words and the accuracy rates in the trochaic prime word condition ($r = .49$, $p < .05$; see Figure 4). No significant relationship was found between the ERP effects and the accuracy rates in the iambic prime word condition.

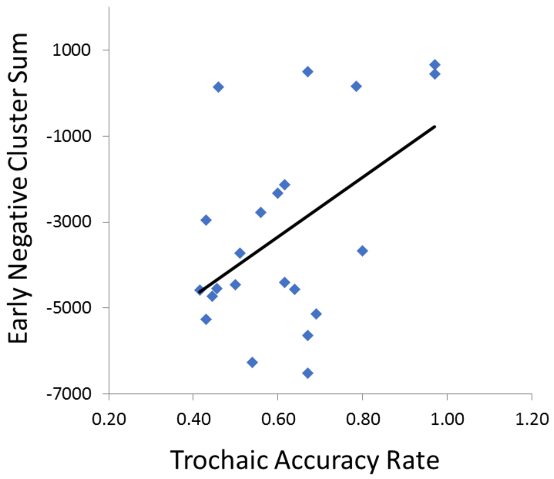

Figure 4. Relationship between rhythm awareness and speech rhythm sensitivity. Correlation between accuracy rates and the early negative cluster sum for the trochaic prime word condition. The solid line represents a linear fit.

CHAPTER FIVE

DISCUSSION

The goals of the present study were to investigate whether speech rhythm sensitivity can be measured separately from speech rhythm awareness (i.e., research question 1) and whether individual differences in speech rhythm sensitivity and/or awareness are significantly associated with reading skills (i.e., research question 2). ERPs elicited by the first "deedee" words were used as a measure of speech rhythm sensitivity while performances on the DEEdee task were used as a measure of speech rhythm awareness. Scores on the English and reading subsets of the ACT were used as a measure of the participants' reading skills. The main findings from this study can be summarized as follows. Regarding research question 1, "deedee" words pronounced with an unexpected stress pattern elicited clear differences in the ERP data. Because the ERPs were analyzed for the first "deedee" word of each pair, these ERP differences were present before the participants heard the second "deedee" word and could give their answer for the DEEdee task. The present findings thus support the hypothesis that speech rhythm sensitivity can be measured separately from speech rhythm awareness. Interestingly, these ERP differences were dependent on the type of stress patterns. Unexpected trochaic "deedee" words produced a negative ERP effect while unexpected iambic "deedee" words were associated with an early negative peak followed by a late negative deflection. Participants' performances on the DEEdee task were low but above chance in deciding which "deedee" word matched the prime word. Surprisingly, they performed better for iambic than trochaic prime words.

Regarding research question 2, the hypothesis was partially supported, with some aspects of speech rhythm awareness (i.e., behavioral performances), but not sensitivity (i.e., ERP effects) found to be significantly correlated with reading skills. In the following sections, these findings are further discussed in light of previous literature, before addressing the limitations of the current study as well as potential directions for future research.

Stress Rhythm Sensitivity and Awareness

The performances on the revised DEEdee task were used as a measure of speech rhythm awareness. Participants' overall mean accuracy on the task was 65%, suggesting that the task was challenging even for adult skilled readers. This finding is within the range of performances found in several previous studies using the DEEdee tasks. For instance, Whalley and Hansen (2006) reported a mean accuracy rate of 63.4%. In addition, participants in Holliman, et al. (2012) answered correctly in 66.8% of the trials. Similarly, Goswami et al. (2009) reported a mean accuracy rate of 67.89%. It is important to note that all these studies were conducted with children. Only one unpublished study reported results in an adult population with and without reading difficulties (Kitzen, 2001). While the accuracy rate for their participants without reading difficulty was much higher than in the present study (88.67% vs. 65%), this discrepancy is difficult to interpret in light of the many differences that exist between the DEEdee tasks used in the two studies.

As discussed in the literature review section, the design and procedure of the DEEdee task varies considerably in terms of prime type (e.g., common nouns vs.

movie titles, book titles, name of characters) and length (single word vs. phrases of various length), as well as in terms of "deedee" word pronunciation (synthetic vs. natural voices) and manipulation (stress pattern only vs. prosodic phrasing). Therefore, the difference in performance across these studies could be due to one or more of these variables. For instance, the DEEdee task used in the present study could have been particularly challenging because speech rhythm cues were provided by only two syllables, making it more difficult for participants to establish a metrical structure. In contrast, studies using phrases as prime stimuli had a total of three to seven syllables (e.g., Kitzen, 2001), thus being more likely to tap into sensitivity to prosodic phrasing rather than sensitivity to metrical stress. One possible way in which future studies could combine both designs is by using prime stimuli composed of only one word but with longer syllable length (e.g., *banAna/deeDEEdee* vs. *MElody/DEEdeedee*) to examine whether performance improves as more metrical context is provided.

When broken down by type of stress patterns, the analyses revealed that the accuracy rate was higher for iambic (M = .69, SD = .16) than trochaic prime words (M = .69, SD = .16). This was an unexpected finding because a vast majority of bisyllabic English words have a trochaic stress pattern (e.g., Carlson et al., 1985), and previous research found that infants developed a preference for the trochaic stress pattern as early as 6 to 9 months of age (Jusczyk et al., 1993). One would thus predict a better performance for prime words associated with the most familiar trochaic stress pattern. However, participants in the present experiment were college students. They are thus likely to have been introduced to Shakespeare's work in high-school and/or in one of the literature courses that are part of the general education requirements at the institution where the study took place. Students are explicitly trained to listen to the iambic pentameter, which is the main rhythmic pattern used by Shakespeare. In addition, it is worth mentioning that participants have been raised within the hip-hop culture, where the iambic pentameter often prevails (e.g., Bradley, 2009). The better accuracy rate observed for iambic words in the present experiment could thus result from explicit instruction as well as increased exposure to this type of stress pattern in later school years. This interpretation also opens new possible research questions regarding when awareness to the iambic stress pattern may become more prevalent than awareness to the trochaic stress pattern as students are exposed to increasingly complex texts in literature courses during the middle and high school years.

Another possible explanation for this discrepancy may lie in the difference in phonetic realization of the "deedee" words used in the present experiment. Previous psychoacoustic and psycholinguistic research suggests that stressed syllables in iambic and trochaic words are realized using different phonetic variations (e.g., Abboud, Boll-Avetisyan, Bhatara, Höhle, and Nazzi, 2016; Hay & Diehl, 2007). Known as the iambic-trochaic law (Hayes, 1995), this account proposes that sounds contrasting in amplitude tend to be grouped initially as stressed, while sounds contrasting in duration tend to be grouped with a final stress. As described in the method section, the stressed syllable (i.e., first syllable) in trochaic "deedee" words was only slightly longer (+15 ms) and slightly louder (+ 5dB) than the unstressed syllable. By contrast, in iambic "deedee" words, the stressed syllable (i.e., second syllable) was significantly longer (+147 ms), but a bit softer (-1.5 dB) than the unstressed syllable. In the present experiment, it is possible that the contrast between the stressed and unstressed syllables may have been more obvious for iambic than trochaic “deedee” words. This aspect can be easily addressed in a replication study by matching the psychophysic properties of the loudness contrast between the stressed and unstressed syllables in iambic “deedee” words to those of the durational contrast between the stressed and unstressed syllables in trochaic “deedee” words.

In the current study, the ERP difference between the matching and mismatching “deedee” words were used as a measure of speech rhythm sensitivity. Statistical analyses of the ERP data were focused on the first “deedee” word following a prime written word. In addition, since both the previous literature (Jusczyk et al., 1993) and the behavioral data suggest differences in sensitivity between the trochaic and iambic patterns, ERP data were analyzed separately for the two types of stress patterns on the prime word. In line with previous ERP studies on speech rhythm perception, the present findings revealed an increased negative ERP component in response to “deedee” words pronounced with a stress pattern that mismatched the prime word (Böcker et al., 1999; Bohn et al., 2013; Domahs et al., 2008; Magne et al., 2007, 2016; Marie et al., 2011; McCauley et al., 2012; Moon & Magne, 2015). It has been argued that this negativity is either part of the N400 family representing an increased load on lexico-semantic processing (Magne et al., 2007), or reflects a more domain-general rule-based error detection mechanism (Rothermich et al., 2010). In the present study, since this negative effect was elicited by pseudowords (i.e., without any meaning), this favors the view that this negative effect reflects a general error detector (Rothermich et al., 2010) resulting from a mismatch between the stress pattern of the “deedee” word and the expectation set by the automatic retrieval of the stress pattern of the prime word. The finding that this priming effect was generated by a written word also further supports the theory that information about the metrical structure of a word is automatically retrieved during reading (Breen, 2014; Magne et al., 2010).

In addition to the negative effect previously discussed, unexpected iambic “deedee” words also produced an early negative difference peaking around 300 ms. Since this early negative effect was not observed for unexpected trochaic “deedee” words, there are two alternative explanations that could account for it. First, as previously argued, if the realization of the stress pattern in iambic “deedee” words was more acoustically salient, unexpected iambic “deedee” words could have been detected by the brain faster and easier, thus leading to an early ERP effect. It is worth noting that this interpretation is in line with the behavioral data showing better accuracy rates for iambic than trochaic prime words. Alternatively, this early effect could simply reflect the fact that the iambic and trochaic stress patterns are realized differently from a phonetic perspective. In line with this second interpretation, Böcker et al. (1999) presented participants with lists of spoken Dutch words in which the last word either had the same or opposite stress pattern. They found that a larger negativity, denoted N325, was elicited by iambic Dutch words, regardless of whether or not the iambic pattern was expected in the word list. The negativity observed in the present study could be regarded as a N325 since it was only elicited by iambic “deedee” words (i.e., a weak-initial stress), and it showed similar latency and frontal scalp distribution as in Böcker et al. (1999).

One final interpretation to consider is that this negativity reflects a mismatch negativity (MMN; Näätänen, 1992). The MMN is an automatic brain response that is produced when there is an unexpected change in acoustic feature (e.g., frequency, intensity, or duration) in a repeated sound sequence. Given that the iambic stress pattern is less frequent in the English lexicon (Carlson et al., 1985), it is possible that iambic words elicit a MMN-like response because native English speakers are less likely to encounter an iambic pattern than a trochaic pattern in everyday discourse situations. This interpretation is further supported by the results of the correlations between ERP data and behavioral performances. Indeed, there was a significant inverse relationship between the size of the early negativity and the performances for trochaic prime words, suggesting that performances on the task were the worst for participants showing the largest early negativity. One could argue that participants with the least language experience, and consequently the least exposure to the iambic pattern, would be the most surprised by iambic words, reflected by a larger MMN. This aspect will need further consideration in a future study. For instance, a measure of oral language proficiency could be used to better understand how sensitivity to different types of stress patterns relate to reading skills.

Relationship among Speech Rhythm Awareness, Stress Rhythm Sensitivity, and Reading Skills

A significant positive association was revealed between the DEEdee task accuracy rates for iambic prime words and the ACT English scores. This finding suggests that students who had better awareness of the iambic pattern, the least common pattern in English (e.g., Carlson et al., 1985), likely had better knowledge of the conventions of standard written English. The ACT English subtest focuses on English punctuation, usage, sentence structure, and grammar. Interestingly, previous studies have reported a link between rhythm perception skills and grammar skills. For instance, Gordon, Jacobs, Schuele, and McAuley (2015) found rhythm perception skills on a non-verbal auditory task accounted for a significant amount of variance in English grammar skills in 6-year-old children. Children with specific language impairment (SLI) have also been found to have comorbid poor rhythm perception skills and grammatical deficits (Gordon et al., 2015). The significant link between English ACT scores and iambic stress awareness may be further supported by the fact that punctuation provides written cues for the underlying prosodic structure of the text (Breen, 2014). For instance, Steinhauer and Friederici (2001) found that commas in texts elicited similar brain responses to intonational phrase boundaries in spoken utterances.

Another significant correlation suggesting a possible role of rhythm perception skills in reading comprehension was found between ACT reading scores and the individual differences in accuracy rates between trochaic and iambic prime words. This result suggests that participants with poorer performance for iambic than trochaic prime words have lower ACT reading scores. The fact that the difference in awareness between the two types of stress patterns, rather than either one separately, correlated with reading comprehension skills, further supports the theory that speech rhythm awareness should not be seen as a single cognitive construct. In addition, future measures of speech rhythm awareness should control for the type of stress patterns in their test items.

While the present findings strongly favor a link between speech rhythm awareness and reading skills, the analysis failed to reveal any significant correlation between the ERP effects (i.e., speech rhythm sensitivity) and any of the ACT scores. Over the past decade, an increasing body of evidence has linked both prosodic sensitivity and prosodic awareness to the development of good reading skills in children (Goodman et al., 2010; Miller & Schwanenflugel, 2008; Schwanenflugel, et al., 2004). Recent research has also investigated whether similar relationships still exist in adult skilled readers and adults with dyslexia (e.g., Dickie, Ota, and Clark, 2013; Mundy & Carroll, 2012). On one hand, some studies revealed that adults with dyslexia show impairments in beat perception tasks, as well as significant correlations between performances on these tasks and various measures of phonological processing skills (e.g., Corriveau, Pasquini, & Goswami, 2007; Hämäläinen, Leppänen, Torppa, Muller & Lyytinen, 2005; Thomson, Fryer, Maltby & Goswami, 2006). On the other hand, several other studies failed to show any significant difference between adults with dyslexia and control groups when using tasks in which the prosodic properties of the linguistic stimuli were manipulated, but no overt prosodic judgement was required to perform the task (e.g., Dickie, et al., 2013; Mundy & Carroll, 2012). For instance, Dickie et al. (2013) used four prosodic information tasks adapted from well-known phonemic processing measures in order to contrast the processes of prosodic sensitivity with skills for prosodic awareness: (a) pig Latin, (b) spoonerisms, (c) picture-matching, and (d) unit-monitoring tasks. They observed no significant differences among reading groups for the picture-matching and unit-monitoring tasks that required accurate perception/sensitivity and representation of prosodic language. Conversely, the pig Latin and spoonerisms tasks required conscious awareness of prosody and elicited significant differences in accuracy among reading groups. Based on this apparent discrepancy between implicit and explicit prosodic tasks, Mundy and Carroll (2012) suggested that adults with dyslexia may indeed have accurate representations of the prosodic structure of words (i.e., prosodic sensitivity), while having deficits in the ability to consciously compare and manipulate these prosodic representations (i.e., prosodic awareness).

Interestingly, this interpretation would be in line with some recent research suggesting a similar deficit for the segmental aspects of phonology. The link between phonological skill impairments and dyslexia has been known for a long time. However, the idea that adults with dyslexia have poor phonological representations (Snowling, 2000) has been recently called into question by the results of several studies showing that poor readers had intact phonological representations, but had a deficit in the ability to consciously manipulate these representations in the context of certain tasks (e.g., Ramus & Ahissar, 2012). In sum, it is very interesting and promising that different lines of research concerning the segmental and suprasegmental aspects of phonology converge toward similar explanation of deficits (i.e., intact representations and impaired ability to manipulate these representations).

Limitations and Future Directions

The present study has several limitations that should be acknowledged. First, ACT English and reading scores may not be fully representative of the participants' reading skills. The ACT is designed to measure college readiness rather than potential reading deficits. In addition, several important components of reading, such as phonemic awareness, decoding, and fluency cannot be teased apart in the ACT reading and English subsets. Future research would use a more comprehensive battery of language and reading assessments to further understand which reading component(s) are more closely related to speech rhythm perception skills.

Second, the DEEdee task, even as revised in the present study, was quite challenging for adults, despite an internal reliability that was much better than in previous studies. This could have stemmed from a more salient iambic than trochaic pattern leading to an inflated rate of correct responses for iambic words (or incorrect responses to trochaic words) and/or to the fact that we used bisyllabic words, which may not be long enough to elicit strong metrical expectations. Another issue to consider is that many participants originated from the southern part of the United States. The linguistic literature shows that Southern American English includes variations in the realization of the stress pattern of many words (Thomas, 2004). In particular, many bisyllabic words that are usually stressed on the second syllable (i.e., police, guitar) are more often stressed on the second syllable. Thus, what were considered "incorrect" answers in the present experiment may simply reflect regional variations in pronunciation. The existence of regional variations is an important aspect that should merit further consideration in future studies, and could have potentially important implications for instructional strategies.

Conclusion

This study was aimed at investigating to what extent speech rhythm sensitivity and awareness relate to reading skills in adults. The present findings support a link between reading skills and speech rhythm awareness, but not speech rhythm sensitivity, thus supporting the hypothesis proposed by Mundy and Carroll (2012) that adult poor readers may have intact prosodic representations but an impaired ability to consciously manipulate these representations. It is important to note that this hypothesis relies primarily on findings from studies using words or short phrases as stimuli. Recent studies have shown evidence for a relationship between reading skills and speech rhythm sensitivity when using longer linguistic stimuli such as sentences or discourses (Brock, 2015; Moon, 2016). It thus remains to be determined how the sensitivity to lexical stress (i.e., at the word level) and metrical stress (i.e., at the sentence level) each contributes to reading abilities in adults. Furthermore, similar studies in children at different grade levels could help better understand how speech rhythm sensitivity and awareness at both the word and sentence levels changes over time, as well as how each relates to the development of good reading skills. Such studies could have important educational implications for instruction and intervention strategies, as the place of prosody remains largely underspecified in current models of reading.

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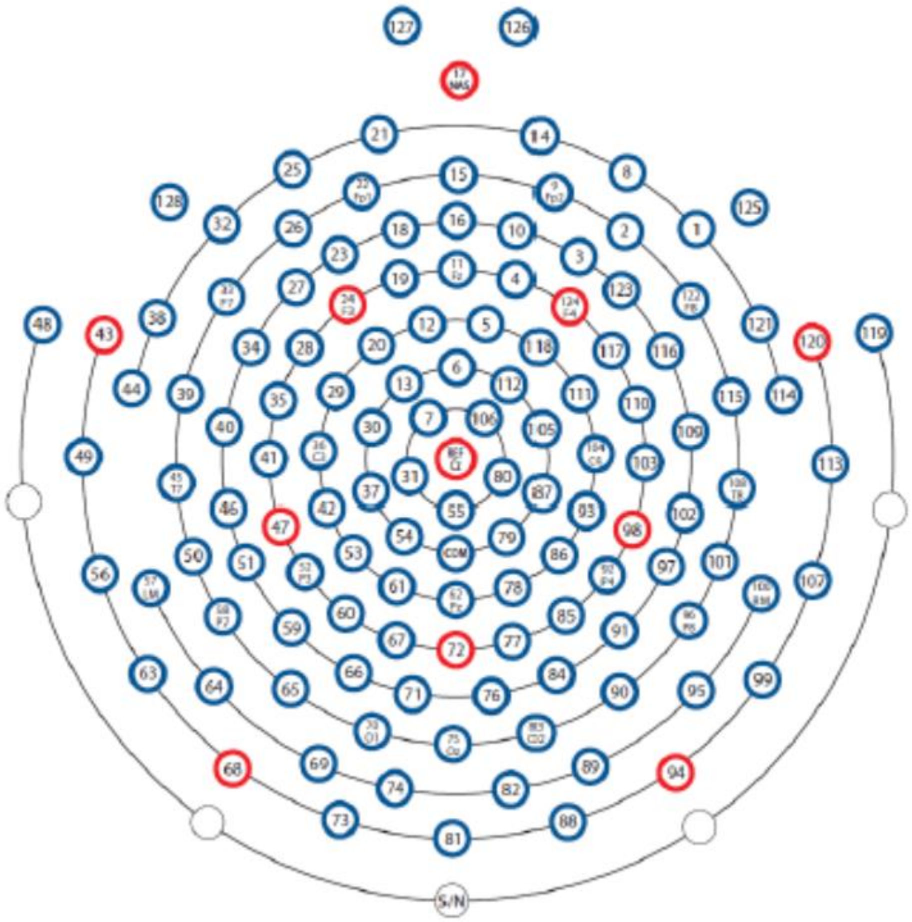
APPENDICES

APPENDIX A

ELECTRODE LAYOUT ON THE SCALP



APPENDIX B

DEEDEE TASK STIMULI WORDS

number	display	report	revenge	disease
body	degree	release	affair	surprise
college	Chinese	amount	idea	expense
apple	Music	attack	command	offense
building	office	review	effect	divorce
mother	model	exchange	account	machine
feeling	letter	copy	advice	return
planet	middle	center	Japan	result
winter	father	woman	supply	device
weather	secret	table	second	event
sister	Friday	bottom	story	respect
pocket	corner	finger	color	approach
spider	daughter	mountain	movie	money
tiger	hunting	doctor	travel	water
career	honey	dollar	station	action
guitar	daddy	Indian	baby	paper
concern	closet	coffee	traffic	magic
award	abuse	uncle	seven	engine
consent	July	lesson	husband	morning
arrest	excuse	helmet	dinner	lady
reward	tonight	percent	parking	brother
support	complaint	campaign	rabbit	captain
design	garage	belief	candy	pilot
advance	regret	repair	defense	jacket
request	control	alert	demand	flower
alarm	inside	technique	mistake	pepper
address	police	assault	hotel	reserve
today	attempt	defeat	success	response

APPENDIX C

IRB APPROVAL LETTER AND CONSENT FORM

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Wednesday, March 30, 2016

Investigator(s): Sang Hee Jung & Cyrille Magne
Investigator(s') Email(s): *sj3c@mtmail.mtsu.edu*
Department: Literacy

Study Title: ***"Relationship between Word Stress Sensitivity and Reading: An Electrophysiological Investigation"***
Protocol ID: **16-2234**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(7) Research on individual or group characteristics or behavior* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification	
Date of expiration	**3/30/2017**	
Participant Size	60	
Participant Pool	**PSY 4240 Students, MTSU Psychology Research Pool**	
Exceptions	Click here to enter text.	
Restrictions	Click here to enter text.	
Comments	Click here to enter text.	
Amendments	**Date**	**Post-approval Amendments** Click here to enter text.

This protocol can be continued for up to THREE years (**3/30/2019**) by obtaining a continuation approval prior to **3/30/2017**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	Click here to enter a date.	Click here to enter text.
Second year report	Click here to enter a date.	Click here to enter text.
Final report	Click here to enter a date.	Click here to enter text.

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:
Click here for a detailed list of the post-approval responsibilities.
More information on expedited procedures can be found here.

Principal Investigator: Sang Hee Jung
Study Title: Relationship between Word Stress Sensitivity and Reading: An Electrophysiological investigation
Institution: Middle Tennessee State University

Name of participant: ____ Age: __________

The following information is provided to inform you about the research project and your participation in it. Please read this form carefully and feel free to ask any questions you may have about this study and the information given below. You will be given an opportunity to ask questions, and your questions will be answered. Also, you will be given a copy of this consent form.

Your participation in this research study is voluntary. You are also free to withdraw from this study at any time. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

For additional information about giving consent or your rights as a participant in this study, please feel free to contact the Office of Compliance at (615) 494-8918.

1. **Purpose of the study:**
   You are being asked to participate in a research study to address fundamental questions regarding the brain mechanisms underlying reading processing.

2. **Description of procedures to be followed and approximate duration of the study:**
   Prior to the start of the experiment, an electrode net with small metal sensors will be gently placed on your head. The sensors will allow us to record the activity from the nerve cells located under your scalp. The sensors are embedded in sponges pre-soaked with an electrolyte solution (water and potassium chloride) to improve the contact with your scalp. The application does not hurt and usually takes about 40 minutes.

   While the electrode net is being setup, you will perform a short music aptitude test during which you will make judgments on pairs of melodies. During the experiment, you will read written words on a computer screen and hear pairs of spoken phrases in which the original syllables have been replaced with the syllable "Dee". Your task will be to decide which "DEEdee" phrase matches the best the way the written word would be pronounced. Both your responses and brain electrical activity will be recorded on a computer. At the end of the experimental session, pictures of your head will be taken in order to determine the exact position of the sensor on the surface of your scalp. The pictures will then be discarded. Afterwards the experimenter will answer any additional questions you have regarding the experiment. The entire session lasts approximately 2 hours, including several planned rest periods.

   We are also requesting access to your ACT scores to determine if there is any relationship between them and your performances during the experiment. Please note that your name and any identifying information will not be linked to your ACT scores in our records.

3. **Expected costs:**
   There will be no cost to you for the data collected for this study. Your insurance company or other third-party payers will not be charged for the research or the examinations required specifically for this study.

4. **Description of the discomforts, inconveniences, and/or risks that can be reasonably expected as a result of participation in this study:**
   The risk involved is minimal. It is no more than one would experience in daily life activities. You will have to sit relatively still for 10 minutes at a time, which might be tiring or annoying. Your hair may be damp at the end of the session from the water-based solution used to lubricate the electrodes, so we will provide you with towels for your convenience. The experimenter will be in constant contact with you, and the experiment can be discontinued at any time.

Middle Tennessee State University Institutional Review Board
Informed Consent Document for Research

5. **Unforeseeable risks:**
   n/a

6. **Compensation in case of study-related injury:**
   n/a

7. **Anticipated benefits from this study:**
   The study is strictly for research purposes and will have no direct medical benefit to you as an individual. This study will address fundamental questions regarding the brain mechanisms underlying reading skills.

8. **Alternative treatments available:**
   n/a

9. **Compensation for participation:**
   If you are currently enrolled in PSY4240 (Behavioral Neuroscience), you will receive 15 points of course credit. If you are a student currently enrolled in PSY1410 (General Psychology), you will receive 4 credits.

10. **Circumstances under which the Principal Investigator may withdraw you from study participation:**
    If you are visually impaired, have hearing deficits, have had psychology or neurological disorders, are not native speaker of English, or have hair extensions that prevent the proper application of the electrode net on your scalp, you may be withdrawn from participating in the study.

11. **What happens if you choose to withdraw from study participation:**
    You may decline to join this study or withdraw from this study at any time without negative consequences; that withdrawal would not in any way affect your standing with the University.

12. **Contact Information.** If you should have any questions about this research study or possibly injury, please feel free to contact Dr. Cyrille Magne at 615-898-5599.

13. **Confidentiality.** All efforts, within reason, will be made to keep the personal information in your research record private but total privacy cannot be promised. Your identity will remain confidential. You will be assigned an ID code, and completed forms will be stored in locked files to which only the Principal Investigator will have access. All computer data files pertaining to you will be accessible by subject ID code only. Your information may be shared with MTSU or the government, such as the Middle Tennessee State University Institutional Review Board, Federal Government Office for Human Research Protections, if you or someone else is in danger or if we are required to do so by law. De-identified version of your data may be made publicly available or shared with other researchers for research purpose only.

14. **STATEMENT BY PERSON AGREEING TO PARTICIPATE IN THIS STUDY**
    I have read this informed consent document and the material contained in it has been explained to me verbally. I understand each part of the document, all my questions have been answered, and I freely and voluntarily choose to participate in this study.

______________________ ______________________________
Date Signature of patient/volunteer

Consent obtained by:

______________________ ______________________________
Date Signature

____
Printed Name and Title